Evaluation of Temporal readout noise in low power CMOS Sensors

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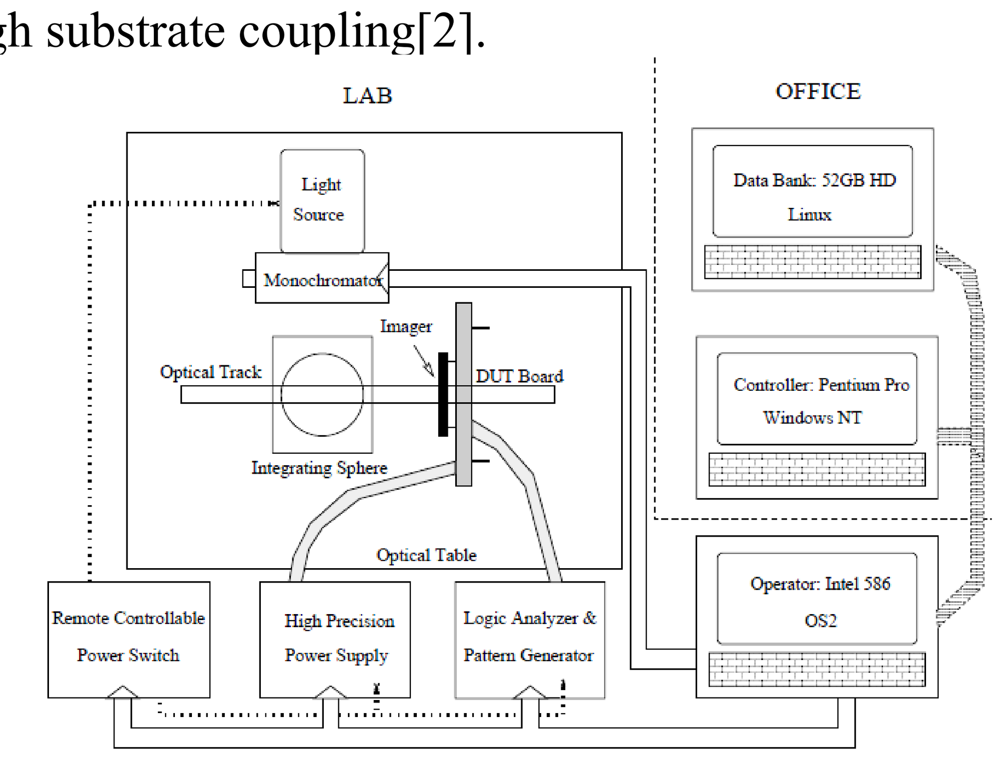
Abstract

Our research currently focusing on image sensors predominantly the sensors implemented using CMOS (Complementary Metal Oxide Semiconductor) technology. These sensors designated as CMOS sensors which were introduced after CCD (Charge-coupled Devices) sensors since CCDs having some drawbacks in terms of its power and making cost compared to CMOS sensors. The most prominent feature of the CMOS sensors is that they can work at low voltage. CMOS sensors need only one supply voltage but CCDs require three to four which makes the cost of the CMOS sensor very low compared to CCD. CMOS image sensors in general have higher temporal noise, higher fixed pattern noise, higher dark current, smaller full well charge capacitance, and lower spectral response, they cannot provide the same wide dynamic range (DR) and superior signal to noise ratio (SNR) that the CCD image sensors have. The Temporal noise of low power CMOS Sensor is evaluated with respect to various pixel sizes and Pixel arrays and corresponding regression analysis applied to obtain the linearity between the input voltage and the power consumed by the sensor in different technical environments.

Introduction

Temporal noise is the temporal variation in pixel output values under constant illumination. Usually temporal noise[1] in image sensors increases when the illumination gets stronger. At the same time the signal also increases, with a even faster speed. As a result the signal to noise ratio (SNR) usually improves as the illumination increases. Since it is SNR, instead of noise, that affects the image quality, the noise effect is most pronounced at low illumination levels. Noise also sets a fundamental limit on image sensor dynamic range (DR), which is another very important image quality metric. There are many sources that can cause temporal noise in CMOS image sensors. Shot noise occurs when photo-electrons are generated and when dark current electrons are presented. Additional noise is added when resetting the photodetector (reset noise) and when reading out the pixel value (readout noise). If the output analog signal is to be digitized, then quantization noise must also be included. Power supply fluctuation can be coupled to the image sensor array and thus cause noise. Noise can also be injected to the sensor from peripheral circuits through substrate coupling[2].



The environmental interferences such as temperature variation, light source humming, electromagnetic field, etc., can cause the fluctuation in the sensor output, and thus cause the temporal noise. Some of the noise can be minimized by good circuit design practice. For example, substrate noise can be reduced by carefully implementing guard rings or by changing the layout. The power supply noise can be reduced by increasing the readout circuit power supply rejection ratio, or by simply using a cleaner power supply. Environmental interferences can be reduced by shielding, cabling, grounding, or by rearranging the whole setup. In the thesis, we are mainly concerned with the intrinsic noise that is generated internally by the CMOS image sensors. The intrinsic noise usually is hard to suppress, and is resulted from the physics of the integrated circuit devices. It includes three major types of noise, namely thermal noise, shot noise, and flicker noise.

Types of Noise

There are many sources that can cause noise in today's integrated circuits, such as power supply fluctuation, EM interference, substrate coupling, etc. Often times these external interferences can be reduced to acceptable level, either by proper circuit design practice, or by carefully applying shielding and grounding techniques. In this subsection we focus on the intrinsic noise that is hard to suppress, including thermal noise, shot noise, and flicker noise.

Thermal noise is generated by random thermally induced motion of electrons in resistive region, e.g., carbon resistors, polysilicon resistors, MOS transistor channel in strong inversion. It is zero mean, and has a very at and wide bandwidth (GHzs) Gaussian psd. Consequently it can be modeled as white Gaussian noise.

Shot noise is associated with the flow of current in diodes and bipolar transistors. It is generated by the fluctuations occurring when carriers cross a depletion region. There must be both a flow of current and a potential barrier to generate shot noise. Shot noise is also modeled as WGN, since it is zero mean, Gaussian and has a very at and wide bandwidth psd.

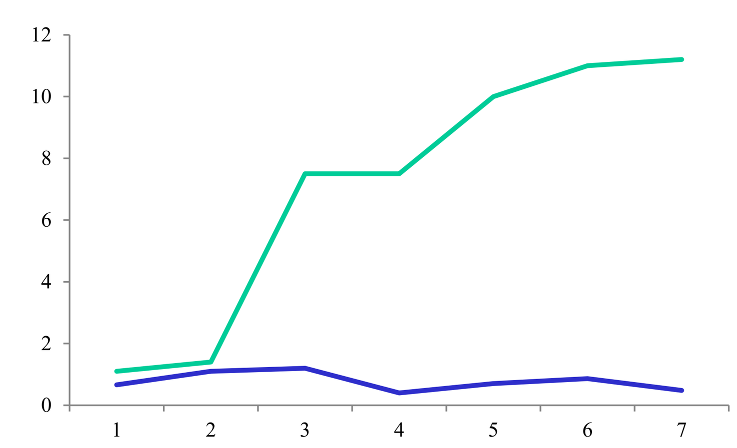
Flicker noise is caused by traps due to crystal defects and contaminants in electronic devices. These traps randomly capture and release carriers, causing carrier number fluctuation. As a result, it is associated with dc current flow in both resistive and depletion regions.

Regression Analysis on Temporal Analysis

SUMMARY OUTPUT

Regression Statistics	
Multiple R	0.291419305
R Square	0.084925211
Adjusted R Square	-0.098089746
Standard Error	0.314336064
Observations	7

Pixel Size (μm)	Temporal Noise
1.1	0.66
1.4	1.1
7.5	1.2
7.5	0.4
10	0.7
11	0.86
11.2	0.48



ANOVA

	df	SS	MS	F	Significance F
Regression	1	0.045849908	0.04585	0.464034	0.526008
Residual	5	0.494035806	0.098807		
Total	6	0.539885714			

	Coefficients	Standard Error	t Stat	P-value	Lower 95%	Upper 95%	Lower 95.0%	Upper 95.0%
Intercept	0.916886279	0.244358263	3.752221	0.013263	0.288743	1.545029	0.288743	1.545029
X Variable 1	-0.020487001	0.030074843	-0.6812	0.526008	-0.0978	0.056823	-0.0978	0.056823

RESIDUAL OUTPUT

Observation	Predicted Y	Residuals
1	0.894350578	-0.234350578
2	0.888204478	0.211795522
3	0.763233771	0.436766229
4	0.763233771	-0.363233771
5	0.712016268	-0.012016268
6	0.691529267	0.168470733
7	0.687431867	-0.207431867

Conclusion

The different types of noise occurs in low power wide dynamic range CMOS imaging sensors is studied in this paper with respect to pixel size. The Temporal noise have been analyzed with various techniques with different pixel pitch and corresponding gain is also observed. A new pixel, featuring a pitch of 7.5 μm and 66% fill factor, has been designed to explore a new way to further reduce the temporal read noise.

References

[1]. S. Wakashima, F. Kusuhara, R. Kuroda, and S. Sugawa, “A linear response single exposure CMOS image sensor with 0.5e− readout noise and 76ke− full well capacity,” in *Symp. VLSI Circuits Dig. Tech. Papers,* Jun. 2015, pp. 88–89.

[2].Y. Chen, Y. Xu, Y. Chae, A. Mierop, X. Wang, and A. Theuwissen, “A 0.7 e−rms-temporal-readout-noise CMOS image sensor for lowlight- level imaging,” in *IEEE ISSCC Dig. Tech. Papers, Feb. 2012,*pp. 384–385.